

**"A NEW CHARACTERIZATION OF SUPERCOOLED CLOUDS
BELOW 10,000 FEET AGL"**
Charles O. Masters

Introduction

The current atmospheric icing, supercooled cloud criteria for the design of U. S. civil aircraft ice protection systems and equipments is presented in Appendix C of Federal Air Regulations (FAR) Part 25 [1]. These design criteria are based upon data developed by the National Advisory Committee for Aeronautics (NACA) in the late 1940 to early 1950 time frame, and were intended primarily for large, high-performance, fixed-wing aircraft of that era. They encompass both layer and convective clouds with altitudes from 0 to 22,000 feet pressure altitude (PA), suggested temperatures as cold as -40° Celsius ($^{\circ}$ C), and liquid water contents (LWC) as high as 2.9 grams per cubic meter (gm^{-3}). Since their generation, these criteria have been exacted upon all aircraft seeking U. S. certification for flight into known icing conditions, including rotary and fixed wing, low-altitude, low- performance aircraft which typically operate below 10,000 feet. Since the phenomenon which dictates the formation of cloud water droplets and their associated LWC are dependent upon horizontal mixing and the vertical development of the cloud above the surface, icing clouds developed within 10,000 feet of the surface under convective conditions will be less severe; i.e., a lower LWC than clouds with developments extending to higher altitudes. Thus, in FY-1979, the Federal Aviation Administration (FAA) engaged the Atmospheric Physics Branch of the Naval Research Laboratory (NRL) to conduct studies and to gather data for a better characterization of the atmospheric icing environment below 10,000 feet. This effort has resulted in the data base employed in the generation of the new characterization of this presentation, and is described in the NRL Report Number DOT/FAA/CT-83/21 entitled, "A New Data Base of Supercooled Clouds Variables at Altitudes Below 10,000 Feet AGL and the Implications for Low Altitude Aircraft Icing" [2].

This presentation introduces the new characterization of supercooled clouds below 10,000 feet above ground level (AGL), and presents the rationale, data analysis, and data reduction procedures employed in the generation of the icing envelopes and other information which constitutes the new characterization. Also, potential applications of the new characterization will be discussed.

The New Characterization

The new characterization of supercooled clouds below 10,000 feet AGL is presented in Figure 1. In essence, it combines both layer and convective clouds, and encompasses three ambient temperature (Ta) dependent icing envelopes of 0 to -15° C, -15 to -20° C, and -20 to -25° C. Associated with the two colder icing envelopes are cloud horizontal extents (durations) of 20 nautical miles (NM), and for the icing envelope of the warmer temperature range, cloud horizontal extents of 50, 20, 12, and 6 NM for LWC ranges of .04 to .5, .5 to .75, .75 to 1.0, and 1.0 to 1.74 gm^{-3} , respectively. Also, associated with the 0 to -15° C temperature envelope are median volume diameters (MVD) which range from 3 to 50 microns (μm) and LWCs which range from .04 to 1.74 gm^{-3} ; for the mid temperature envelope MVDs range from 5 to $38 \mu\text{m}$ and LWCs range from .04 to $.66 \text{ gm}^{-3}$, and for the coldest temperature envelope, MVDs range from 7 to $15 \mu\text{m}$ and LWCs range from .04 to $.41 \text{ gm}^{-3}$. The outermost edges of these envelopes and the horizontal extents represent extreme values of supercooled cloud properties determined to a probability level of exceedence of less than one part in a thousand; i.e., less than 0.001.

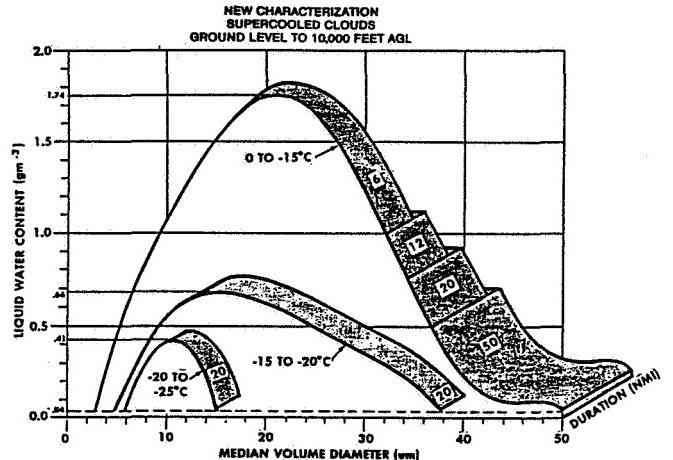


Figure 1. The new characterization of supercooled clouds from ground level to 10,000 feet AGL

General Approach

The basic approach employed in these analyses for the new characterization was to determine values of LWC, MVD, Ta, and event duration such that the probability of independently exceeding any one of these parameters would be less than one part in a thousand; i.e., < 0.001 for all atmospheric icing conditions up to 10,000 feet AGL over the conterminous U. S. and nearby offshore areas. The initial analysis effort consisted of reviewing all icing events in raw data form in 5°C temperature increments from 0 to -25°C for each parameter of interest. These parameters were then ordered by magnitude and the 99.9 percentile selected.

Thus, values which exceeded the 99.9 percentiles would correspond to values of those parameters with a probability of exceedance less than 1 part in a thousand. Obviously, such a simplistic approach could only be employed and yield results with a high level of confidence in cases where there is a symmetrical, unimodal near-infinite data set from which to draw. However, in this case, the data base of 6,700 plus data miles representing some 1,400 icing events was deemed marginal, especially for extreme parameter values which were typified by limited data miles. Thus, realizing the possible limitation of the raw data set, a least distribution was employed to predict the extreme values. Details of this procedure are contained in the technical report noted in Reference [3].

A Combined Presentation for Layer and Convective Clouds

In FAR 25, Appendix C, the presentations of LWC, temperature, MVD, and horizontal extent (duration) are presented separately for layer clouds (continuous maximum conditions) and for convective clouds (intermittent maximum conditions). A review of the new characterization's data base in terms of layer clouds versus convective clouds indicates that the ranges of cloud properties were similar for both cloud types except for LWC's 1.0 gm^{-3} which were found only in convective clouds and, for Ta colder than -17.5°C where only layer clouds were observed. This is delineated in the matrix of Figure 2, which shows Ta versus LWC for each cloud type. A further review of the horizontal extents (icing events durations) for each cloud type revealed that combining the two cloud types into a single presentation would not be overly restrictive provided due consideration was given to the proper cloud type; e.g., the horizontal extent

of 6 NM for LWC greater than 1.0 gm^{-3} is based only upon convective cloud data. Thus, this was the approach taken.

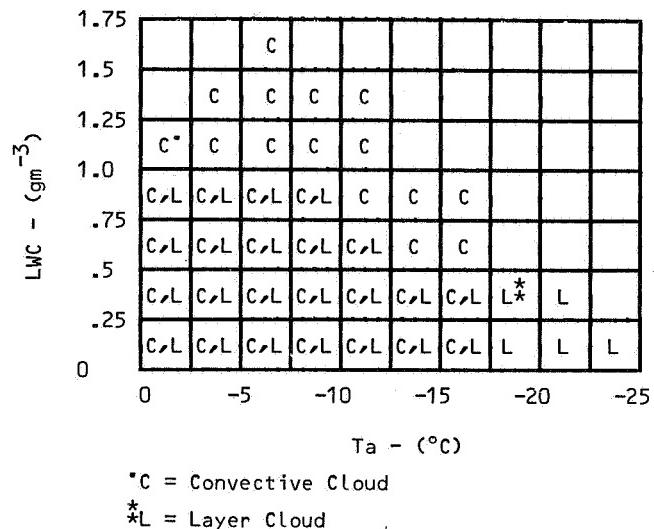


Figure 2. Matrix of LWC versus ambient temperature (Ta) for cloud types

A Consolidated Temperature Range: 0 to -15°C

Initially, raw data graphs were constructed for each of the 5°C temperature intervals between 0 and -25°C in a manner similar to the LWC versus MED graphs of FAR 25, Appendix C. The maximum observed values of LWC which occurred in each $5 \mu\text{m}$ interval of MVD was used to establish an interim envelope outline for each of the temperature ranges. The one exception is the one lone maximum data point which occurred at $22 \mu\text{m}$ at a LWC of 1.7 gm^{-3} , and a Ta of -6.5°C , which was omitted from the interim envelopes. These raw data graphs revealed very little differences between the three envelopes in the 0 to -15°C temperature interval (see Figure 3). Consequently, it was decided to combine all data in the 0 to -15°C temperature range and establish one envelope which described these parameters. Rationale for the inclusion of the one lone data point of 1.7 gm^{-3} to this temperature range could be supported if, during subsequent analysis, this point was found to lie within the Weibull 99.9 percentile. This semblance was not observed in the temperature ranges of -15 to -20°C and -20 to -25°C . Consequently, parameters in these ranges were treated separately.

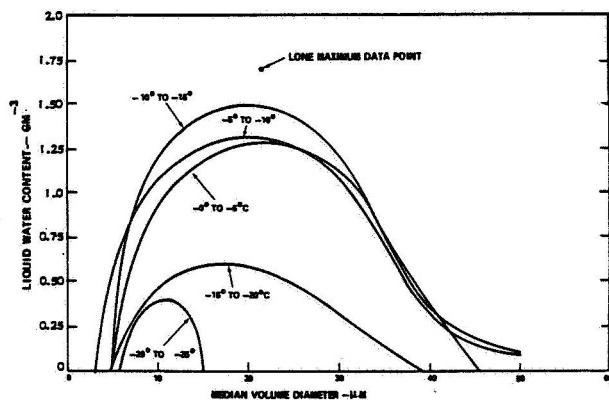


Figure 3. Similarity of icing envelope of 5°C intervals for the temperature range of 0 to -15° C.

Ambient Temperature versus Altitude AGL

An initial review of the data base indicated no appreciable altitude dependence for the cloud properties of LWC and MVD. However, icing conditions were not observed at the colder temperatures which occurred at the higher and lower altitudes; i.e., temperature in the range of -15 to -25° C which occurred between ground level and 4,000 feet AGL and between 6,000 feet and 10,000 feet AGL (Figure 4). However, this region constituted only a small portion, approximately 16 percent, of the total temperature versus altitude envelope and, for all practical purposes, could be accommodated by assuming the probable existence of supercooled clouds at all temperatures of interest and at

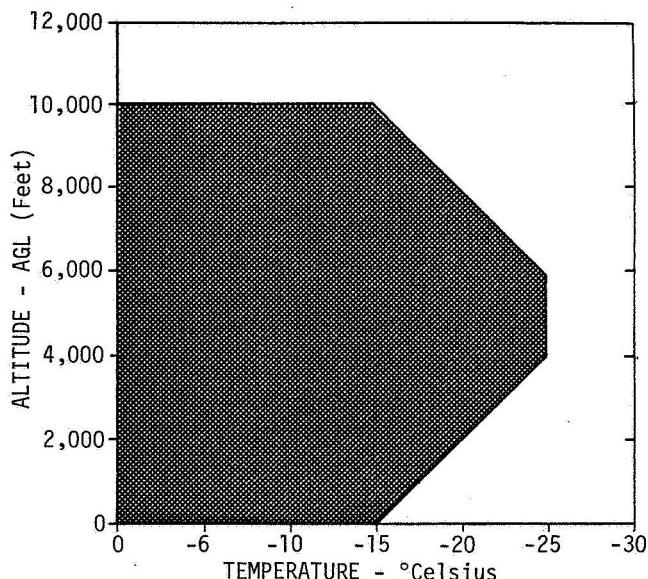


Figure 4. Ambient temperature versus altitude above ground level for observed cloud types

all altitudes up to 10,000 feet AGL. (Possibly over the northernmost portions of the U. S. during outbreaks of extreme cold polar air masses.) Consequently, the new characterization does not present a temperature versus altitude chart, whereas FAR 25, Appendix C, presents such a chart for both the continuous maximum and intermittent maximum criteria.

The Weibull Distribution

In these analyses, the Weibull distribution function was employed to predict the extreme values of the supercooled cloud properties. This function reduced to the form

$$\ln(\xi) = \ln \ln \left(\frac{1}{1 - \pi} \right)$$

was employed to establish the coordinates of the plot of the parameter of interest: where

π = the i th percentile of an observed cloud property; i.e., 20, 50, 60, . . . 99

ξ = the value of an observed cloud property; e.g., LWC, associated with the i th percentile.

Most extreme values of the new characterization were determined by computer; however, for illustration purposes, Figure 5 graphically depicts the procedure employed in determining the extreme value of cloud horizontal extent (duration) associated with the icing envelope of -15 to -20° C.

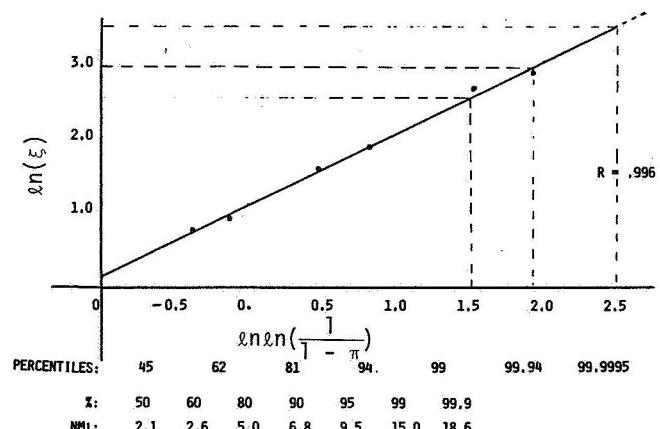


Figure 5. The determination of horizontal extent extreme: -15 °C to -20° C.

Although in this case the observed 99.9 percentile value was 18.6 NM the Weibull predicted value was found to be 20.1 NM and was subsequently rounded off to 20 NM as depicted on the new char-

acterization (Figure 1). In a similar manner, the other extreme values of the cloud properties were determined, except that the Weibull predicted values of LWC were determined for each 5 μm MVD interval of its associated icing envelope.

A Final Comparison

Figure 6 presents a comparison of the new characterization, FAR 25, Appendix C, and the recently introduced FAA rotorcraft directorate's limited criteria. On this chart, all temperatures have been converted to Celsius, and the -40° F temperature contour line of the FAR 25, Appendix C, intermittent maximum criteria has been omitted, pri-

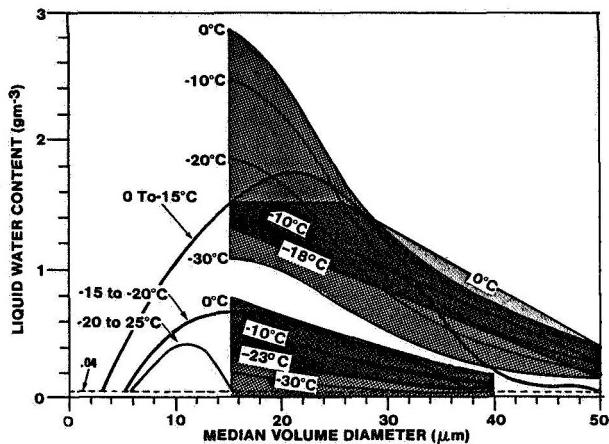


Figure 6. The new characterization superimposed on the far 25, Appendix C, and the rotorcraft directorate's limited intermittent and continuous criteria.

marily for clarity. Some of the readily apparent observations/conclusions that can be drawn from this chart are:

1. The new characterization encompasses MVDs between 3 μm and 15 μm which were omitted from the FAR 25, Appendix C, and the rotorcraft directorate's limited criteria.
2. The new characterization presents a maximum LWC value of 1.74 gm^{-3} at 22 μm , whereas the FAR 25, Appendix C, criteria depicts a maximum value of 2.9 gm^{-3} at 15 μm , and the rotorcraft directorate's limited criteria depicts a maximum value of 1.5 gm^{-3} .
3. The new characterization depicts no temperature colder than -25° C , whereas the FAR 25, Appendix C, criteria presents temperatures as cold as -30° C and suggests temperatures as cold

as -40° C , and the rotorcraft directorate's limited criteria coldest temperature is -23° C .

4. In the intermittent maximum criteria of both the directorate's limited criteria and the FAR 25, Appendix C, criteria, all values of LWC associated with MVD's larger than 36 μm significantly exceeds those of the new characterization and are deemed excessively conservative for altitudes below 10,000 feet AGL.

Concluding Remarks

Figure 1 depicts the final characterization of the atmosphere for supercooled clouds from ground level to 10,000 feet AGL. The envelope of each of the temperature ranges encompass values with a probability of exceedance greater than one part in a thousand, whereas the extremes of the envelopes represent exceedance probabilities less than or equal to one part in a thousand. Inherently, this characterization has parameters which may be employed in subsequent design of ice protection systems and equipments for aircraft which operate between ground level and 10,000 feet AGL. It is planned that this characterization will serve as an adjunct to the worldwide characterization of supercooled clouds currently under development.

References

1. Federal Aviation Regulation Part 25 (FAR 25), *Airworthiness Standards: Transport Category Airplanes, Appendix C, Washington, D.C. 20591, Department of Transportation, Federal Aviation Administration, 1974.*
2. Jeck, R. K., *A New Data Base of Supercooled Cloud Variables at Altitudes Below 10,000 Feet AGL and the Implications for Low Altitude Aircraft Icing, Department of Transportation, Federal Aviation Administration Report Number FAA-CT-83-21, 1983.*
3. Masters, C. O., *A New Characterization of Supercooled Clouds Below 10,000 Feet AGL, Department of Transportation/Federal Aviation Administration, Report Number FAA-CT-83-22, 1983.*

**"DEVELOPMENT OF A PLAN FOR IMPROVED AIRCRAFT ICING
FORECASTS AND ASSOCIATED WARNING SERVICES"**

Ralph Pass

I would like to describe a plan that has just recently started at the Office of the Federal Coordinator for Meteorology (OFCM). The plan was suggested by the National Transportation Safety Board (NTSB), and the goal is to provide integrated plans for improving aircraft icing forecasts. Before people panic and think we are going to come up with a new plan in a vacuum, I would like to say that I'm going to take whatever I can from various plans that already exist covering the various phases of the aircraft icing forecast problem. Yesterday, we heard a description of the FAA's plan from Loni Czekalski, which will be included in the OFCM plan. As a result, the aircraft certification part of my effort will be rather straightforward. Again, we are going to try to develop a plan that will summarize a systems view of what the Federal Government should be doing in aircraft icing and associated warning service dissemination. We have broken it down into five major areas dealing with the data collection, forecasting, dissemination, display and education, and aircraft certification.

Building on what has been said this morning, the FAA is now looking at new characterizations of clouds. The question becomes, "How do you relate that to aircraft icing?"; "Does the aircraft manufacturer have to give you a formula which says that given this droplet size and liquid water content, this is the kind of icing you can expect for a given air speed?" This might be a reasonable thing to look at. If that is the case, then the question becomes, "How do you get information to the pilot relating to liquid water content and droplet size?" Currently there are no forecast procedures for that. There is currently no way to conveniently display it; and based upon discussions between the Icing Committee and the Remote Detection Committee, there is no way to measure it. So, this type of plan with this kind of problem needs to be addressed coherently from a systems point of view. We are going to be looking at not only what goes into each of these five areas, but also their interconnection. If the FAA would like to require liquid water, for example, as one of the parameters, the pilot needs to know it before he takes off, and we are going to have to figure out how to get it to him. That is what the plan would like to address.

I would like to give you a brief layout of what will be done. Task 1, which I have not yet addressed, is basically a literature search and interview period. Part of my reason for briefing here is to identify people to whom I should be talking in each of those areas we mentioned earlier. I certainly want to welcome anyone who would want to talk. Just let me know.

Briefly, the project schedule goes like this. We started in the first of October through the collection phase, Task 1, and it should be finished the end of this month or the first part of next month. At that point, we will start interviewing people throughout the country and throughout the various agencies interested in these areas, which will lead to a series of reports characterizing each of the individual areas we will address. We, then, have several months in order to put the report together and have it reviewed. Within approximately one year from that point, we hope to have a final copy out.

A literature search has been run at the OFCM and at TASC. Anyone who would like to make sure that certain pieces of information are included are welcome to let me know. One of the things I would like to get hold of fairly soon is the AFGL report on comparing current procedures for forecasting icing. Again, the forecast procedures are probably as conservative as the FAA characterization of clouds in the envelopes in FAR 25 Appendix C.

I would like to interview relevant individuals. If you would like to be included or know of others you would like to have interviewed, please submit your name or names of all relevant individuals. Finally, we would like to prepare a plan outline, which will be available in November at the OFCM. If you would like to see that, please contact either myself or Manny Ballenzweig, and we will see that you get a copy of it.

The first task is to see that we are pointed in the right direction. I don't intend to work in a vacuum. We would like to take the bits and pieces from the various groups and come up with a final integrated plan. Thank You.